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Evaluation of ERTS-1 Image Sensor
Spatial Resolution in Photographic Form

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Type II
Progress Report 6

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Section 1

INTRODUCTION AND SUMMARY

This report describes progress on this contract during the period 1 March 1973 to 1 September 1973. Work reported during this period in Type I reports has not been re-reported here but has been referenced where necessary.

All computer programs for handling of the microdensitometer magnetic tapes, data organization, data calibration, and matching of ERTS-1 scan data to U-Z underflight scan data have been made operational. Two sets of imagery from 11/29/72 and 1/4/73 are at the stage of optical transfer function (OTF) generation. A total of six sets of imagery are being acquired, from August 1972 to October 1973. A time profile of the OTF over this 14 month period will be possible at the end of our analysis.

Computer compatible tapes for ERTS-1 imagery from 4/4/73 have been ordered for the purpose of determining any additional image degradation in the corresponding system corrected photographic product.

Section 2
RADIOMETRIC CALIBRATION FOR IMAGERY

Discussion

The Fourier theory of image formation with incoherent light is derived in terms of scene radiance and image irradiance. These two quantities are to be measured from the U-2 underflight image and ERTS-1 image, respectively. Since absolute calibration is impossible for all practical purposes, relative exposures are used which differ from the absolute exposures by at most a multiplicative and/or additive constant. The relative exposure is measured from step tablets exposed onto the film of interest. Specific details and examples for the ERTS-1 and underflight calibration are given in the following two sections.

ERTS-1 Calibration

Curves of microdensitometer density and transmission versus relative exposure are shown in Figs. 1, 3, & 4. These are for the data sets of 11/29/72 and 1/4/73. The density and transmission values are averages of a few hundred measurements made in each step, after anomalous data points have been replaced (see Progress Report 5). The measured range of imagery values is also indicated for each band.

The curves of transmission versus exposure indicate the success of ERTS-1 processing in obtaining a linear relation between the two quantities. Because the microdensitometer has been calibrated to give a constant Callier Q factor (see Progress Report 5), this linearity is maintained for both specular and diffuse film measurements. In further analysis of the ERTS-1 image data, the transmission values are used directly.

Underflight Calibration

Microdensitometer density and transmission versus exposure are shown in Figs. 2 & 5. A simple linear relation does not apply to these data as in the case of the ERTS calibration. The conversion to exposure was chosen to be made from the density exposure curve, because a linear approximation between sample points (i.e. 2 steps of the step tablet) gives a better fit than for the transmission-exposure curve.

The step tablet used for the U-2 film is a 21-step tablet filtered similarly to the imagery. It is assumed in generating the exposure points for these data that the original tablet is standard (density range = 0.05 - 3.05) and has a density increment of 0.15 between steps. The exposure for each step is then assumed proportional to the transmission of the original tablet at that step.

Section 3

MICRODENSITOMETER APERTURE CALIBRATION

Discussion

The sampled data from the microdensitometer are points off the convolution function of the scanning aperture with the photographic image. If the illumination at the sample is incoherent (a point to be questioned (Kinzly,1972), but assumed to be true here), the aperture is described by its irradiance distribution and the film by its intensity transmission in the convolution process.

Because it was not possible to scale the slit *width* exactly between the the underflight and ERTS-1 scans, the data must first be deconvolved, to obtain the true photographic image, before further analysis. The deconvolution is effected by:

1) density → transmission data conversion
2) Fourier transform of data
3) division of data spectrum by aperture OTF
4) inverse Fourier transformation of true data spectrum

Examples

The irradiance profile (line spread) of the microdensitometer aperture can be obtained by differentiating a scan of a perfect edge function.
For our data a partially transmitting metal edge is scanned each time the scan aperture is changed. These scans are shown in Figs. 6-9. They are not smooth because of quantization in the plots. The corresponding derivatives are also shown in Figs. 6-9 . Since direct differentiation (e.g. finite differences) amplifies noise, a combination smoothing and differentiating function (Lanczos, 1964) was used for these data. The asymmetry of the spread functions for the larger apertures was not expected and is being investigated.

The Fourier transform of the line spread function gives the optical transfer function (OTF) for the scan aperture. These are shown in Figs. 10 & 11 and are the functions used in step 3 above. The scale between the underflight and ERTS-1 images is 8X or less and therefore only the frequency ranges of interest are shown.

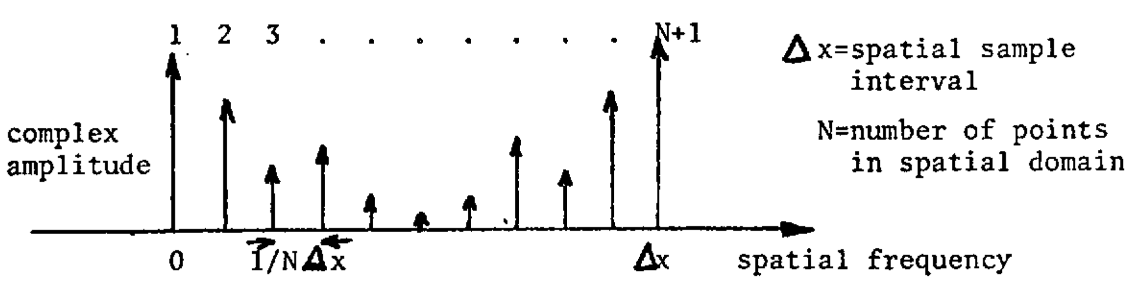
Section 4

SCALING AND MATCHING OF UNDERFLIGHT TO ERTS-1 IMAGERY

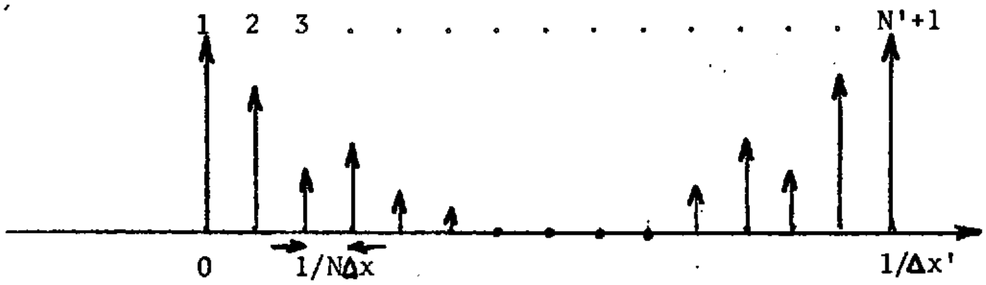
Discussion

When the two sets of imagery are scanned with a microdensitometer, the aperture length (i.e. the length perpendicular to the scan direction) is scaled as closely as possible to cover the same general ground area in the underflight and ERTS-1 images. Endpoints of the scans are determined by prominent ground features to insure the same ground caverage. However, the scan data are sampled and digitized when recorded. Thus when a section of this data is analyzed, the starting point in each image must be determined to be the same ground point (matching) and, since the sample intervals of the microdensitometer system cannot, in general, be changed by multiples of the exact scale between the images, one set of image data must be scaled in some way to correspond to the ground coverage of the other set of image data.

Since these operations must be performed in a discrete way (sampled data) it is necessary to have the same number of points in each set of data for comparison purposes. The scaling operation can be done in several ways, linear or polynomial interpolation being one (Schowengerdt and Slater, 1972). A technique with more theoretical validity is being evaluated for the ERTS-1 analysis. The approach is based on the following considerations. The spectrum of discrete data appears as below:



The spectrum is replicated at $1/_{\Delta x}$ and sampled at $1/_{N\Delta x}$. Suppose that N is increased by adding zeros between the replicated spectra:



The sample interval in the frequency domain remains the same, but the sample interval in the spatial domain has effectively decreased,

$$\Delta x' = \frac{N}{N'} \Delta x$$

Since $N\Delta x$ has not changed, the same range of spatial data is sampled but at a smaller interval. Figure 12 illustrates the technique. A smooth function was sampled at 8 points and its discrete Fourier transform taken. Then 8 zeros were inserted into the spectrum as above, and the inverse transform calculated. The final data consists of the original 8 points with 8 interpolated points. The interpolation is of the sinc $(x) = \sin(\pi x)/\pi x$ type (Goodman, 1968).

For image scaling, the underflight data has been scaled to match the ERTS-1 data, rather than visa versa, because the underflight scans, being made with a large aperture, are generally smoother and less disturbed by granularity than the ERTS-1 scans. The procedure is presently,

1) Select the same number of points over approximately the same ground area in both the underflight and ERTS-1 scans
2) Calculate the Fourier spectrum of each

3) Insert zeros in the underflight spectrum, one at a time, and inverse transform.

4) Compare the ERTS-1 data with the interpolated underflight data to find an optimum scale and shift. The evaluation is currently done by finding the mean square difference between the functions at each scale and for various possible shifts of the ERTS-1 data relative to the underflight data.

5) The procedure (steps 3, 4) is repeated until a minimum mean square difference is found.

6) Exact matching sets of the two scans can then be chosen from the data by taking equal number of points, starting at the same point, in each scan.

The result for one pair of scans is shown in Fig. 13. These are from scan 1 of ERTS-1 image # 1129-18181 (see Progress Report 4) and the corresponding U-2 underflight image. The underflight scan was interpolated ("stretched" in a sense) as above. The improved match can be discerned near the ends of the scans. The spatial frequencies in each scan then correspond exactly, and the ERTS-1 OTF can be obtained as a direct ratio of ERTS-1 and underflight image spectra.

Current Status of Acquired Imagery

Set	Flight Date	Aircraft (A/C) Vinten	Aircraft (A/C) Scanner	Aircraft (A/C) # Frames	ERTS-1 MSS	Microdensitometer scans
1	8/22/72 8/23/72 Arizona	✓	NA	184	✓	-
2	11/29/72 San Francisco	✓	✓*	18	✓	✓
3	1/4/73 San Francisco	✓**	✓*	51	✓	✓
4	4/4/73 San Francisco	✓	✓*	48	✓	in progress
5	6/15/73 San Francisco	✓	on order	75	on order***	-
6	Requested for 10/73	on order	not requested		ID not available yet	-

* Scanner data not suitable for analysis because of severe geometric distortion arising from the lack of a gyrostabilized platform on the A/C.

** Band 001 (green) malfunction, no imagery.

***ERTS-1 imagery of San Francisco was not acquired on 6/15/73. Therefore imagery from the previous (5/28/73) and following (7/3/73) cycles and from the adjacent 6/14/73 pass have been ordered.

Current Status of Analysis

Calibration, matching, and scaling are in progress for the data from 11/29/72 and 1/4/73 and most of the data is at the stage of generating OTF's. CCT's of ERTS-1 image # 1255-18183 (4/4/73) have been ordered. This data will be compared to the system corrected MSS photographic product to determine the amount of image degradation introduced in the EBR-photographic steps.

Acknowledgements

Mead Technology Laboratories (Dayton, Ohio), an Industrial Associate of the Optical Sciences Center, is performing the microdensitometer scanning for this contract.

ERTS Frames Studied

Data Set	Frame #'s	Bands
11/29/72	1129-18181	4, 5, 6
1/4/73	1165-18173, -18175	5, 6

Data Requests Submitted

Date	Frame #'s
6/25/73	1255-18174, -18181, -18183
10/30/73	1309-18174, -18181
	1326-18121, -18124
	1345-18172, -18174

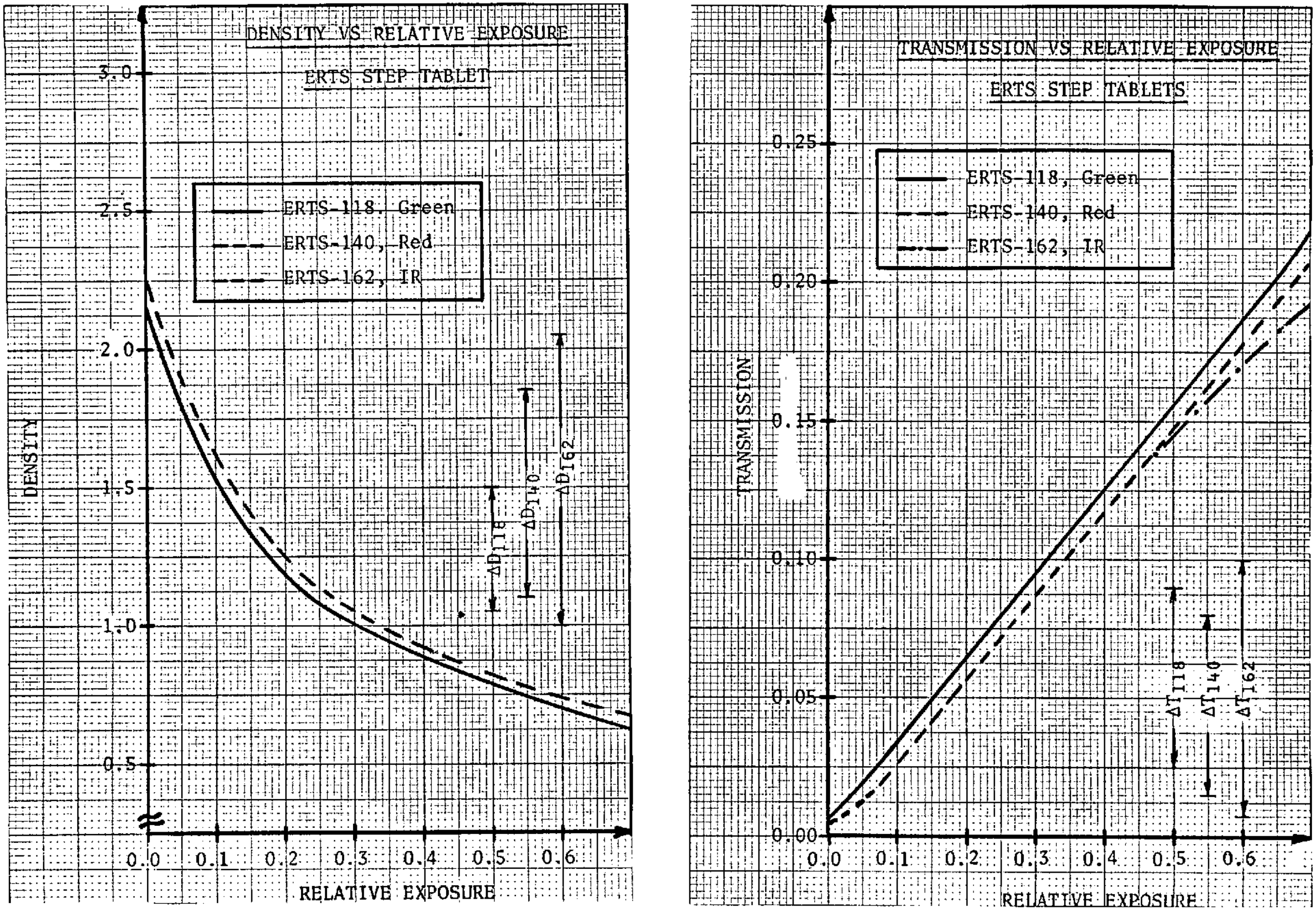
REPORT SUMMARY

Evaluation of ERTS-1 Image Sensor Spatial Resolution
in Photographic Form

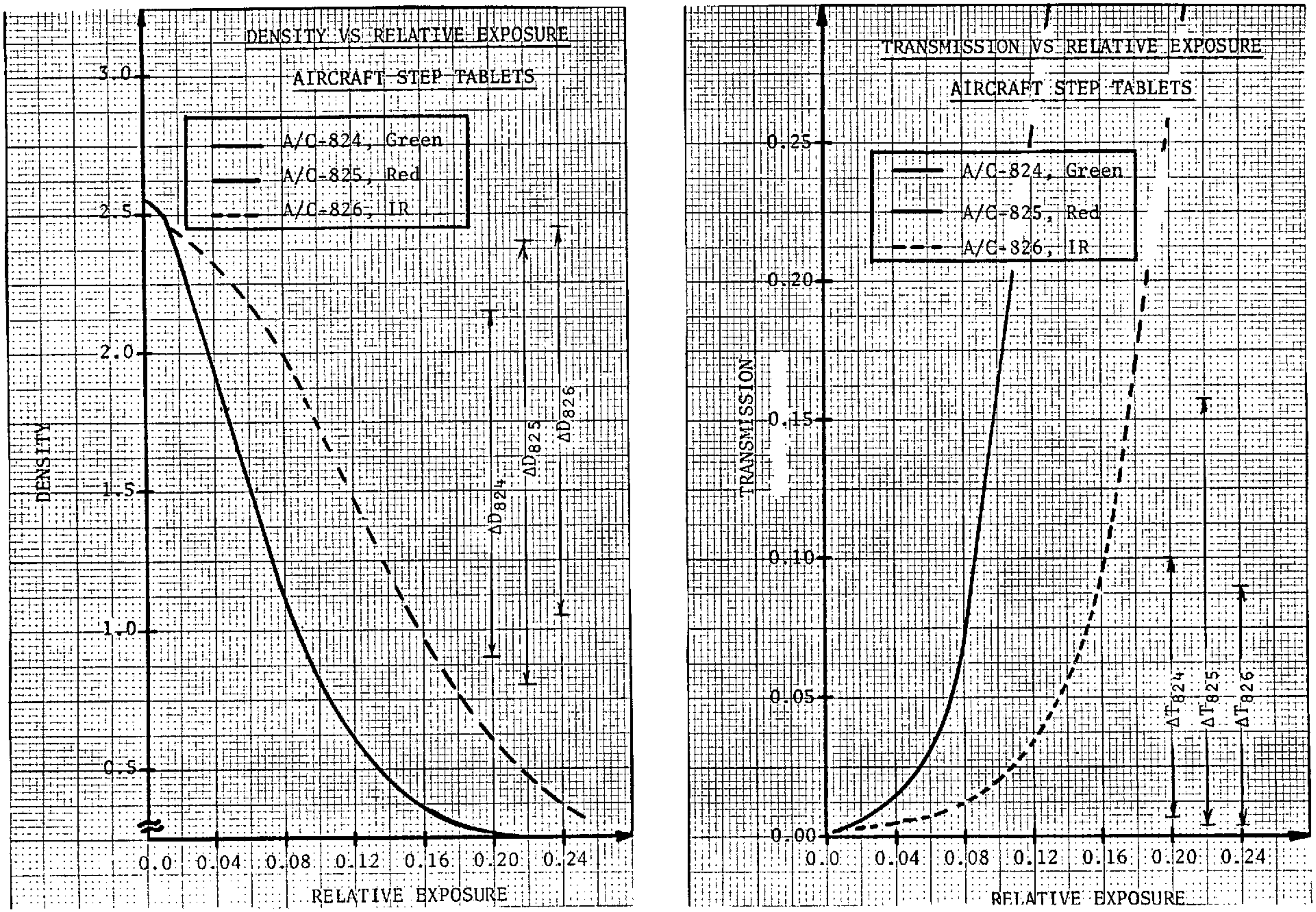
Type II Report # 6

Category 9a - Sensor Technology

This report describes progress on contract number NAS5-21849, during the period 3/1/73 - 9/1/73. Calibration of the microdensitometer aperture used for image scans is described. Radiometric calibration, scaling, and matching of underflight to ERTS-1 imagery are described and results presented. Image acquisition, which is nearly complete for our project, is brought up to date.

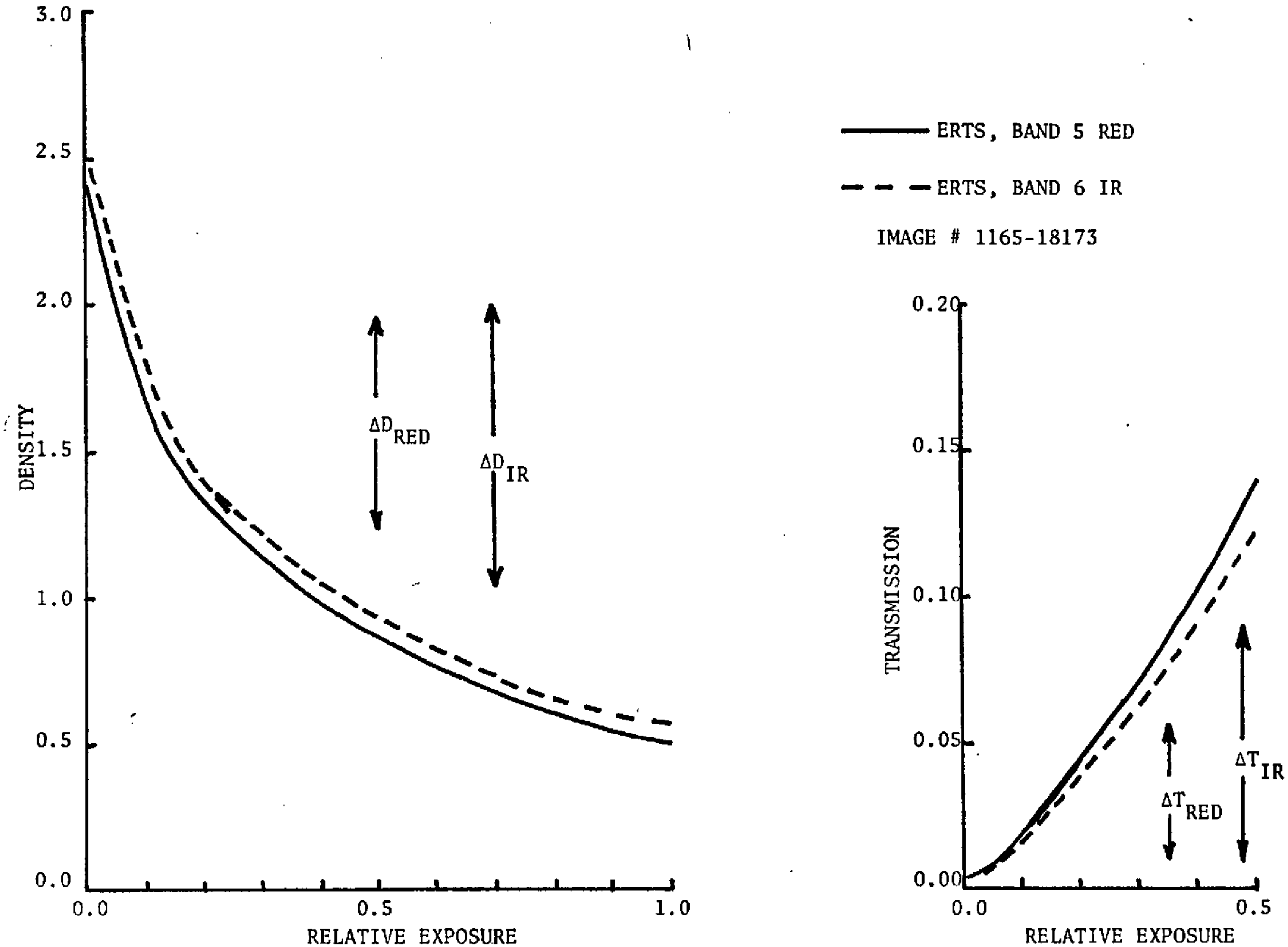


EXPOSURE CALIBRATION (11/29/72 IMAGERY)
Figure 1

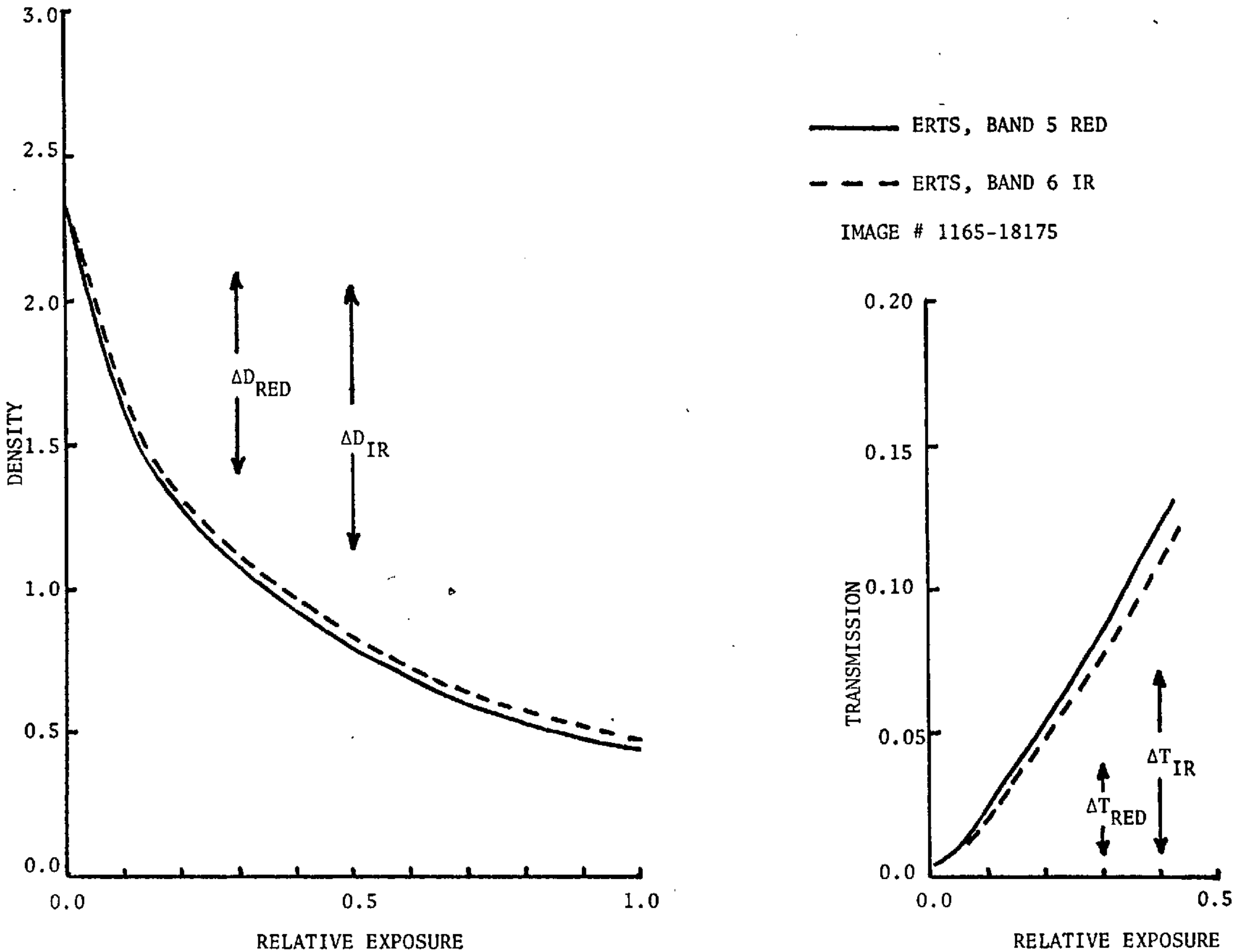


EXPOSURE CALIBRATION (11/29/72 IMAGERY)

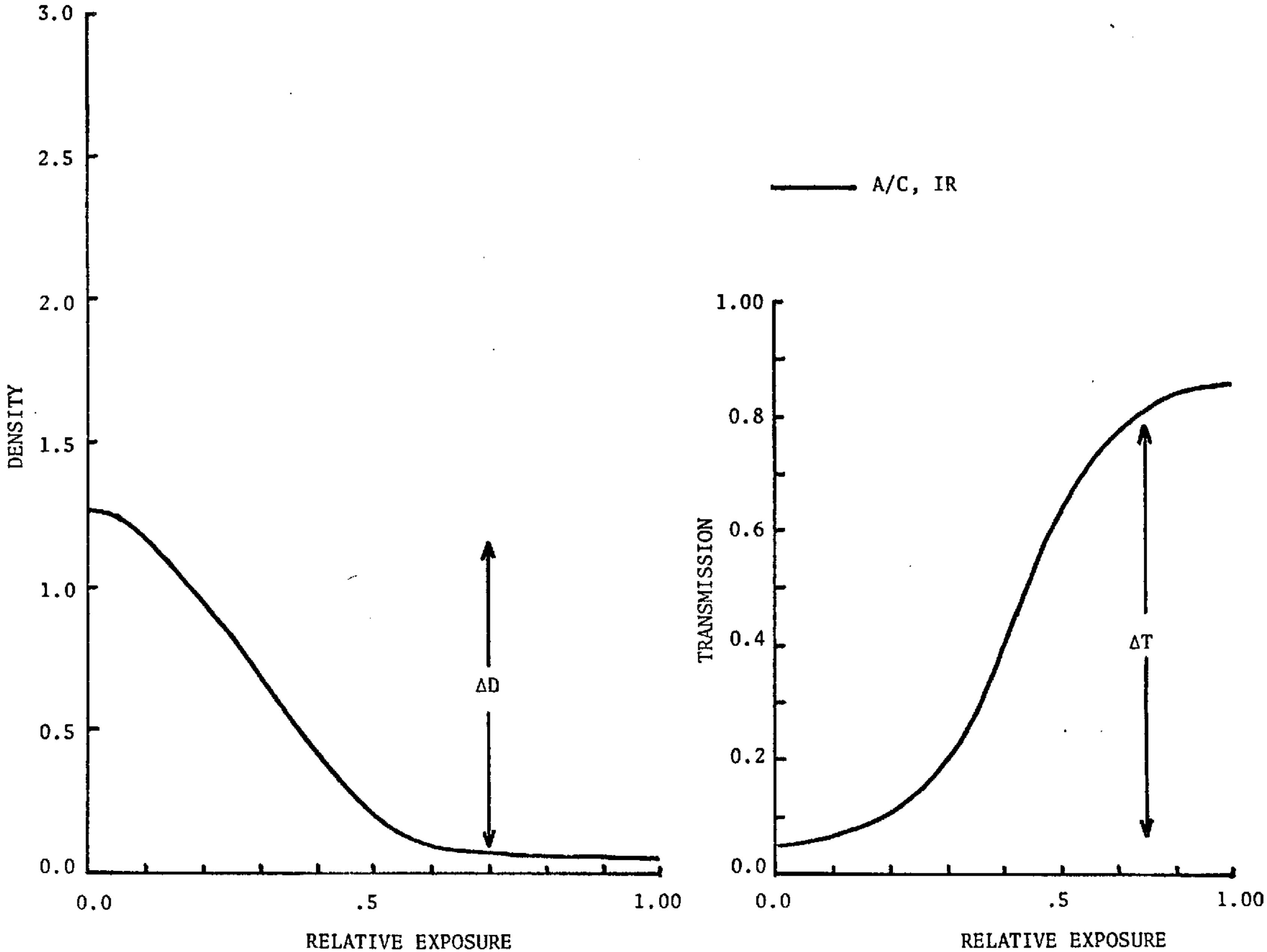
Figure 2



EXPOSURE CALIBRATION (1/4/73 IMAGERY)
Figure 3

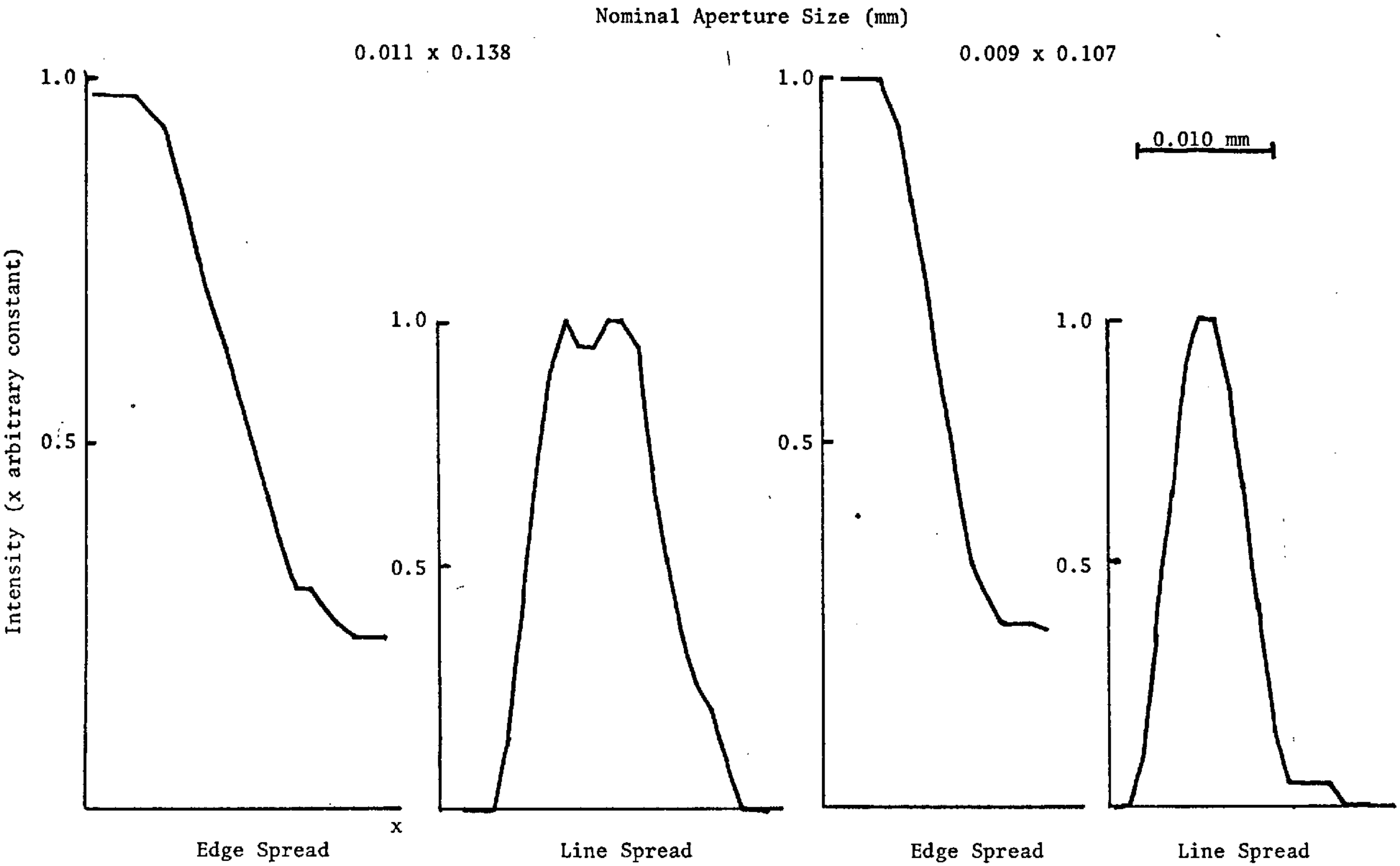


EXPOSURE CALIBRATION (1/4/73 IMAGERY)
Figure 4



EXPOSURE CALIBRATION (1/4/73 IMAGERY)

Figure 5

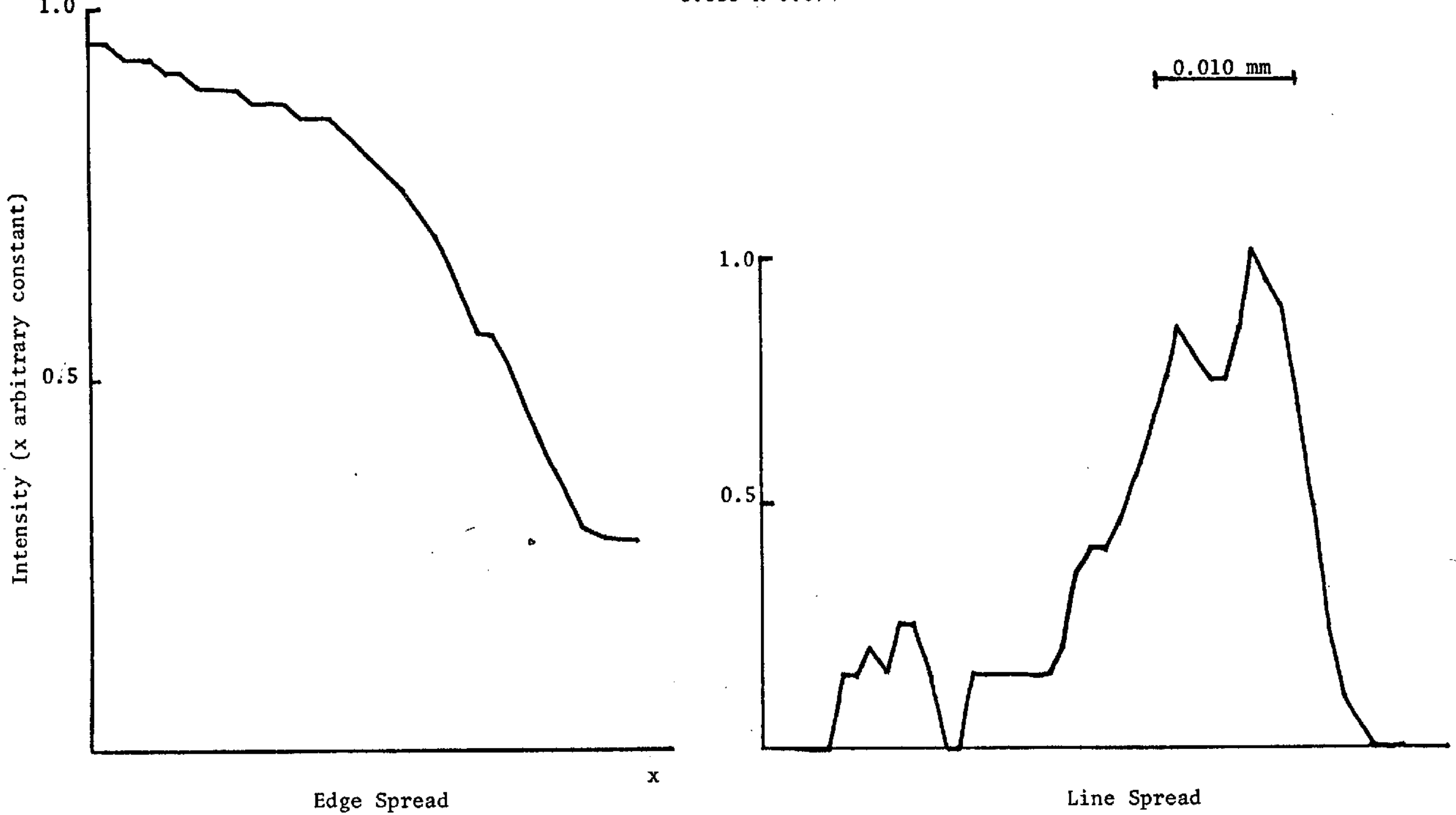


SCAN APERTURES FOR ERTS IMAGE (11/29/72)

Figure 6

Nominal Aperture Size (mm)

0.035 x 0.874

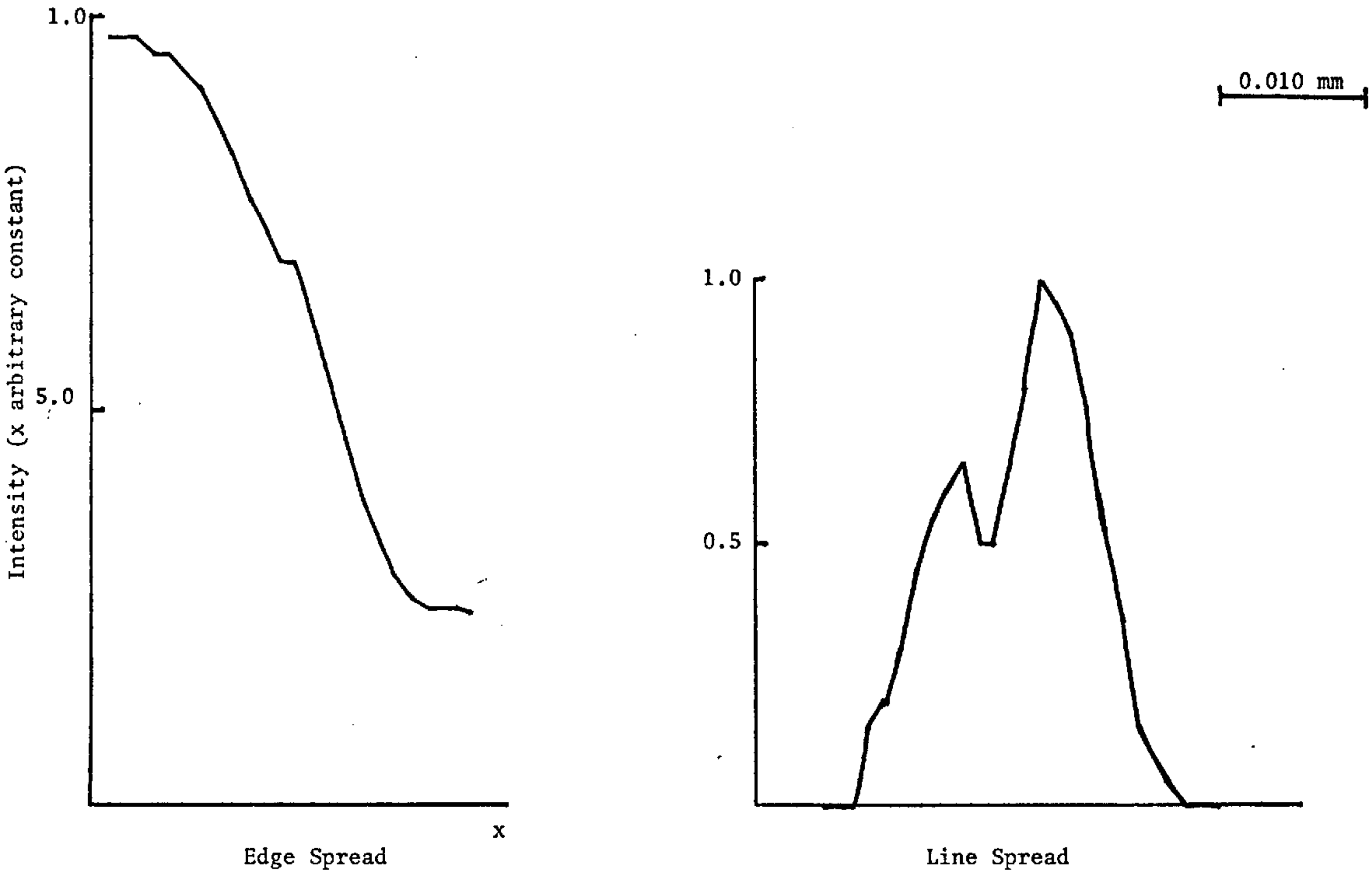


SCAN APERTURE FOR U-2 IMAGE (11/29/72)

Figure 7

Nominal Aperture Size (mm)

0.024 x 0.138



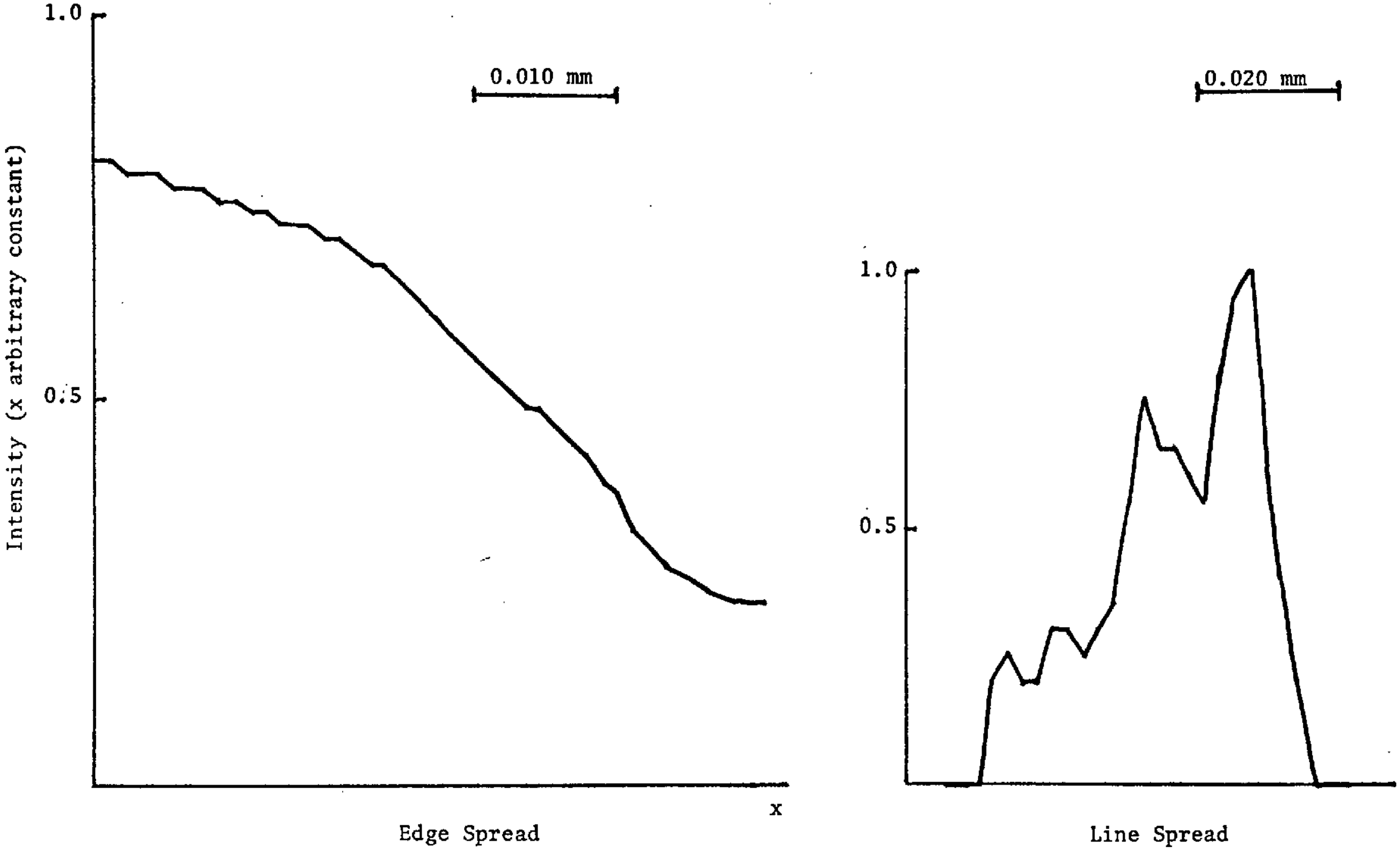
SCAN APERTURE FOR ERTS IMAGES (1/4/73)

Figure 8

.48 x 1000

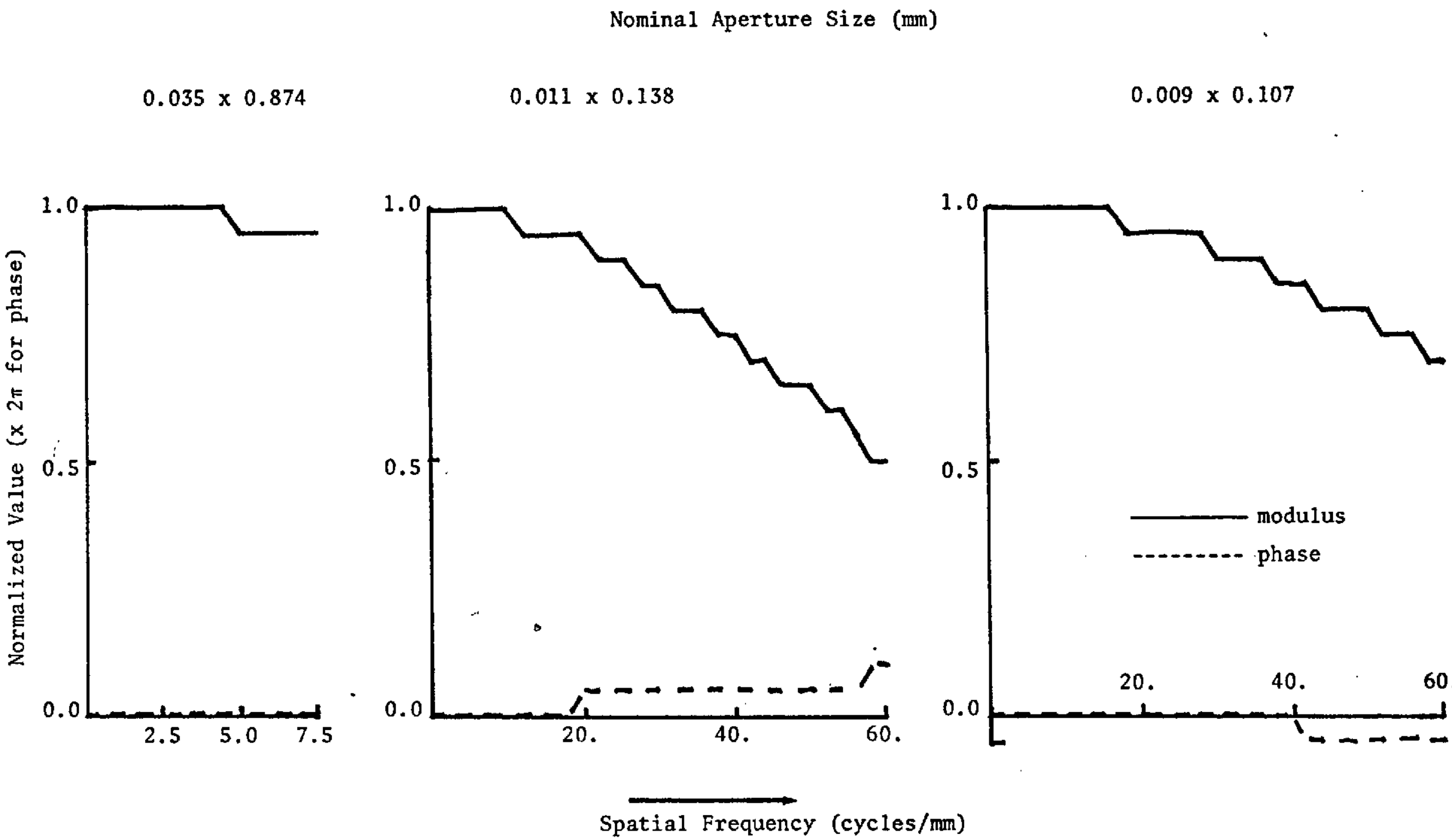
Nominal Aperture Size (mm)

0.048 x 1.000



SCAN APERTURE FOR U-2 IMAGE (1/4/73)

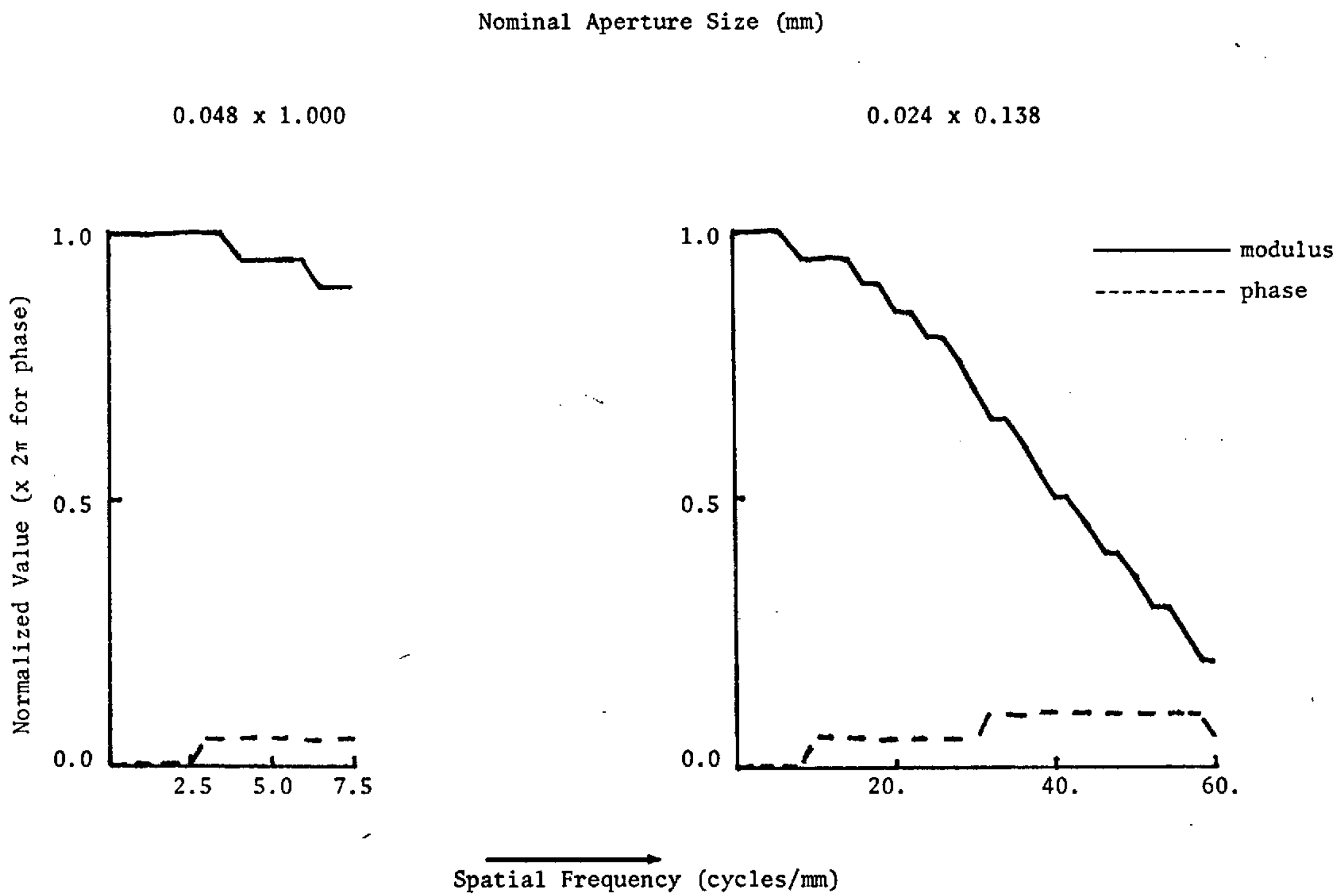
Figure 9



SCAN APERTURE OTF'S

(11/29/72)

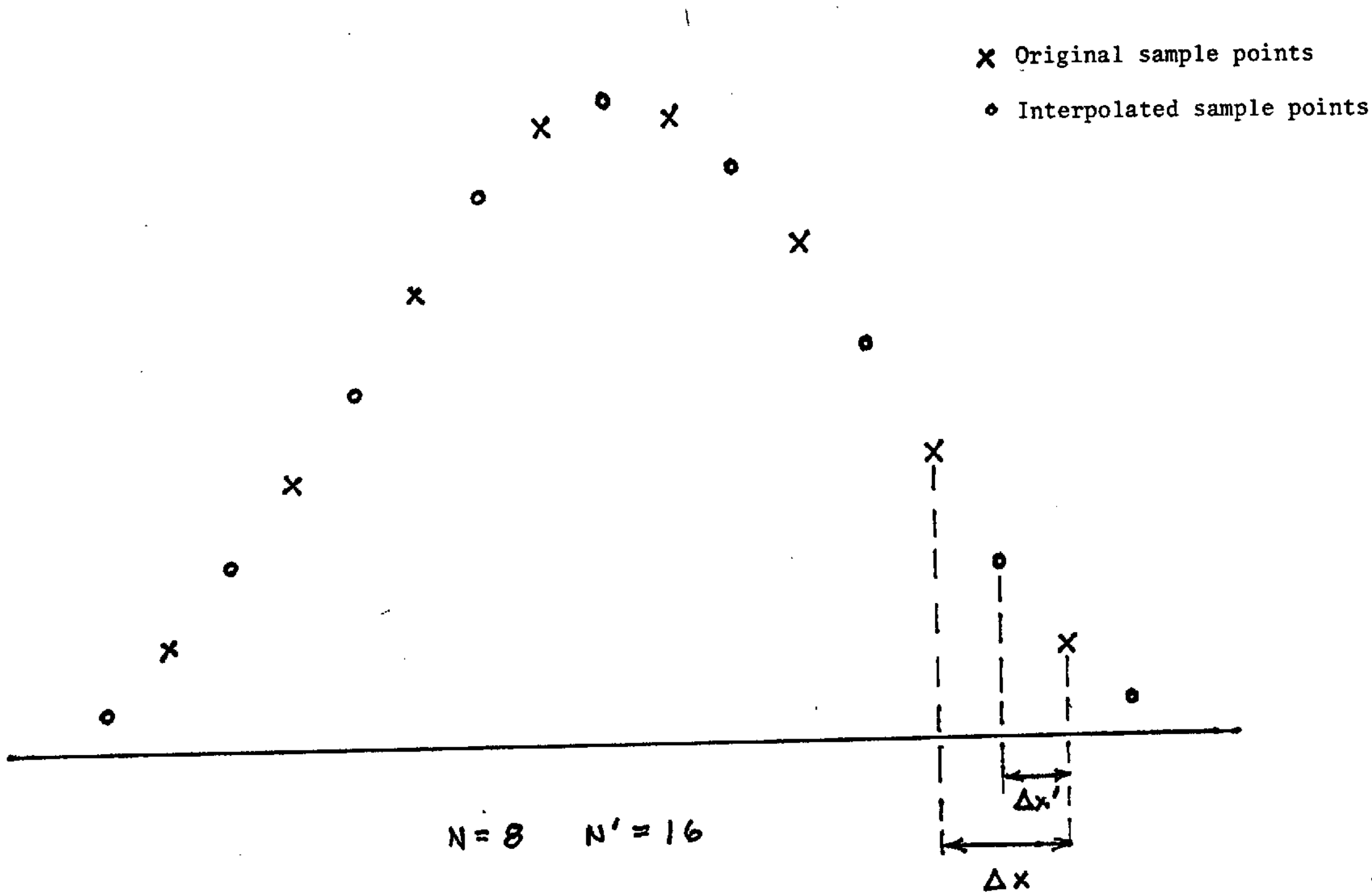
Figure 10



SCAN APERTURE OTF'S

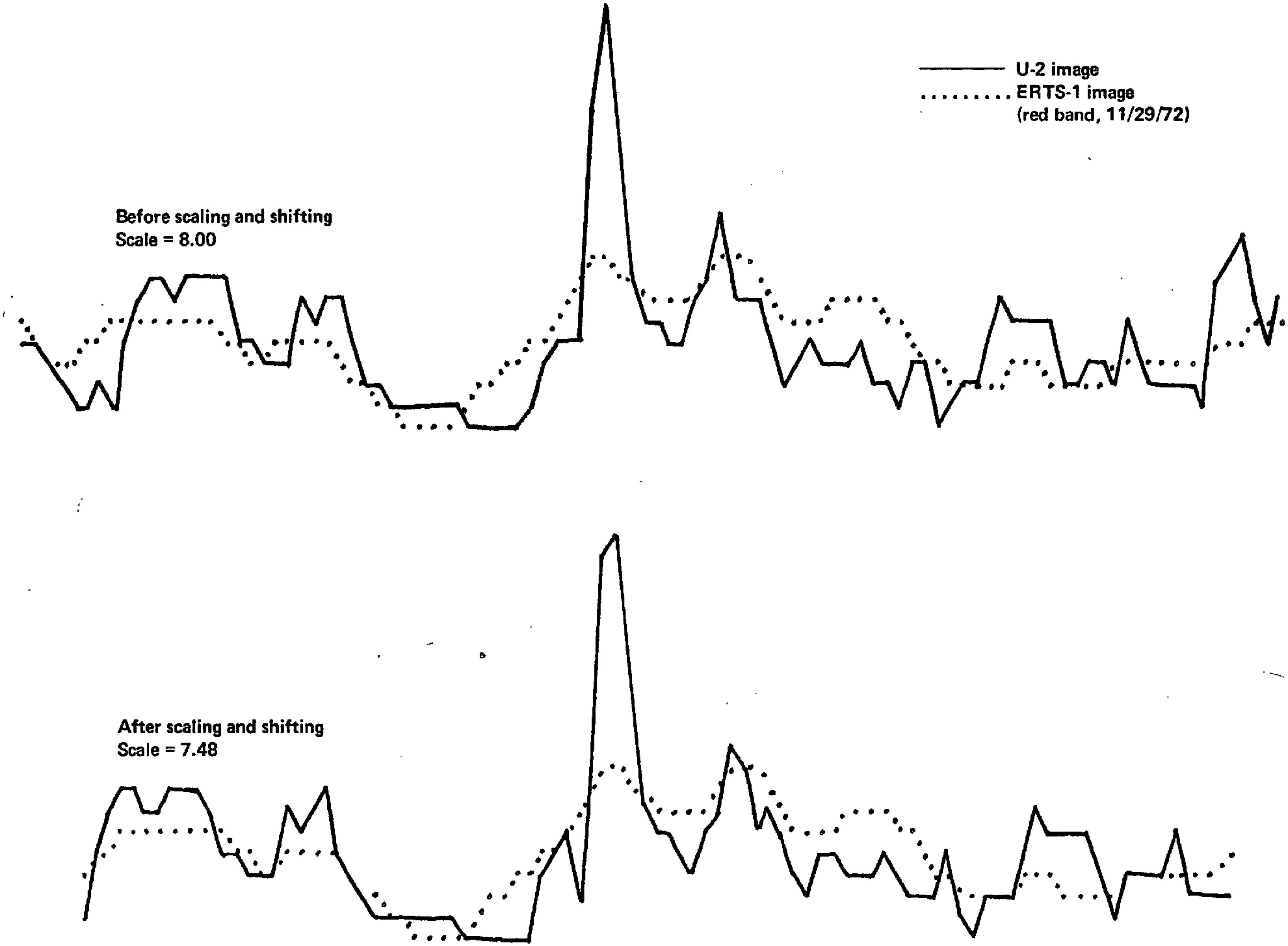
(1/4/73)

Figure 11



FOURIER INTERPOLATION

Figure 12



MATCHING OF OBJECT AND IMAGE
Figure 13

REFERENCES

Goodman, J. W., *Introduction to Fourier Optics*, McGraw-Hill, 1968, p. 25.

Kinzly, R. E. , "Partially Coherent Imaging in a Microdensitometer," J. Opt. Soc. Am., 62(3):386-394, March 1972.

Lanczos, C., *Applied Analysis*, Prentice Hall, Inc., Third Printing, 1964, p. 321.

Schowengerdt, R. A. and Slater, P. N., "Determination of the Inflight OTF of Orbital Earth Resources Sensors," presented at the ICO-IX Congress on Space Optics, Santa Monica, California, Oct. 1972.